On the observation of strain before and after the occurrence of rock-falling.

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By

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Abstract

At the end of 1954, a part of adit was broken and rock-falling taken place nearby the observatory, wherein having been investigating the extensometric and tiltmetric activity. By the record indicated before and after occurrance of cave in, it might be concluded that the omen of rock-falling could be noticed on the variation of nearby rock strain and ground-tilt respectively long before the accident.

1. Introduction.

In order to observe crustal movements, the Disaster Prevention Research Institute of Kyoto University had set up a observatory in the adit of old copper mine located at Ide-cho Tsuzukigun, Kyoto pref. (See the Fig. 1.) providing with an Extensometer (7 components), a High Magnification Extensometer (3 components), a Tiltemeter and a Discharge Meter, by which the slightest variation of these, such as strain, ground-tilt on earth and the discharge of water in the mine, are recording automotically.

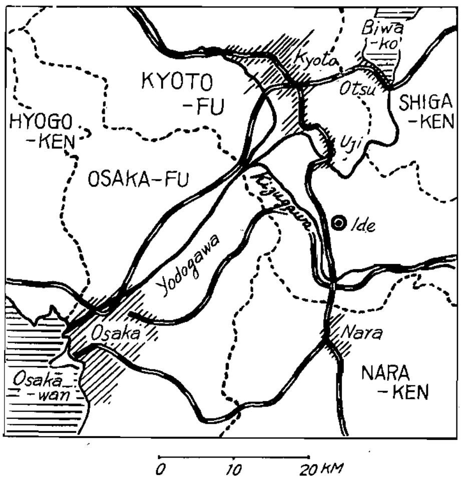


Fig. 1. Position of the observatory.

At the end of 1954 it happened incidentally rock-falling from a part of adit. The following explanation is made according to survey based on the record indicated before and after the event.

2. The outline of observatory and rock-falling.

The adit of this observatory, as shown in Fig. 2, had been dug on the hillside with 1.3 m. wide and 1.8 m. high respectively, and the old adit is said to be excavated some 80 years ago and the new one being dug from January to April 1954 and the observatory room situates inside of adit at the spot about 50 meters from the pit mouth of former and 120 meters from that of latter and 30 meters depth under the surface of the earth surrounded with mica schist. The variation of interior temperature of the observatory room is so narrow as indicated within 0.5°C. through year round.

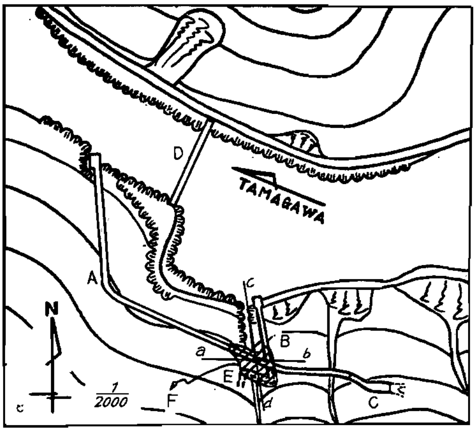


Fig. 2. Plane figure of the observatory and location of rock-falling.
A : new adit, B : old adit, C : observation room, D : dam, E : dead adit, F · location of rock-falling

The place where the rock-falling occurred, which was extending over 15 meters, was at the position adjacent to junction of old and new adit just beneath the valley. This part of adit was said to be very dangerous due to the nature of rocks is so brittle that the concrete lining shoud have been applied at the time of excavating.

The first rock-falling has begun from December 24th 1954, the volume of which is as large as about 2 or 3 m³. and continued alike on 25th with 5 m³. and in the night of 26th 30-40m³. rock fell. Although the fragments in the

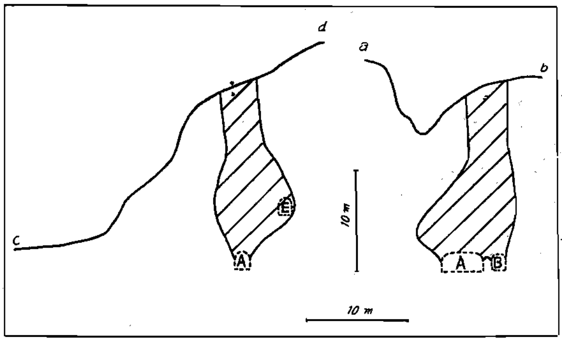


Fig. 3. State of rock breakage on the location of rock-falling. (vertical section a-b and c-d)
A : new adit, B : old adit, E : dead adit.

beginning were small they became gradually larger day after day and seemed to have reached at 100 m^3. according to the estimation deduced from the result on the record of lst January 1955. (afterward the following fact was discovered that another dead adit had running nearby through obliquity in parralell to the adit about 4 m. upward of the place of rock-falling.) Presumably occational rock-falling has been continuing thereafter through there is no way to acknowledge. The operation to carry the fragments out of new adit had been done at the rate of 15 m^3. per day from 10 th of January until interrupted by an openning (4 meters in diameter) came out on the hillside on 17th January.

After two days suspension, the work resumed again and we could safely get into observation room on 31st January for the first time after rock-falling taken place. Of course, onece a while we had sneaked into adit under dangerous condition removing the rocks aside and investigated the status of the rock breakage, which seemed to have been broken extending to about 450 m^3. as is shown in Fig. 3.

3. Observation measuring instruments.

The Extensometer fitted up in the observation room is called "Super-Invar-

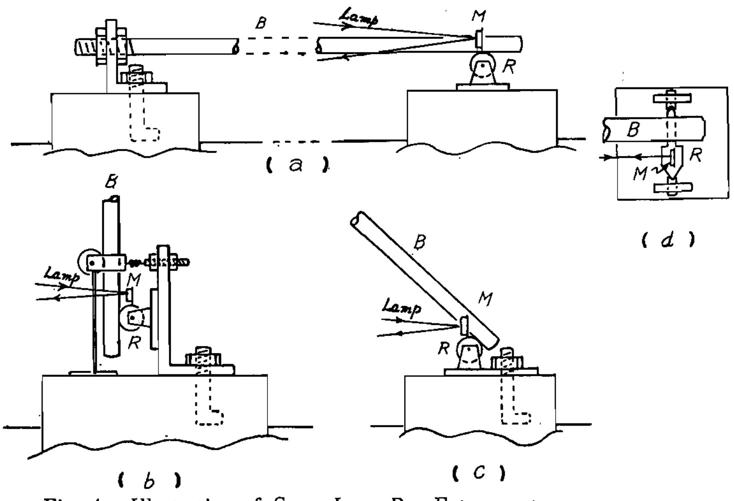


Fig. 4. Illustration of Super-Invar-Bar Extensometer.
B : Super-Invar-Bar, M : mirror, R : roller
(a) Take a side-view of horizontal component (components 2, 3, 6)
(b) Take a side-view of vertical component (component 1)
(c) Take a side-view of sloping component (components 4, 5)
(d) Take a bird's-eye view of roller of horizontal component

Bar Extensometer" (as shown in Fig. 4.) The one end of this bar (1 cm. in diameter) is fixed to a rockwall and the other end is put on the roller which is also fixed on the wall. Thus the extension rate is to be transmitted to the roller which reflects on the mirror attached to roller, and recorded by optical magnification.

The High Magnification Extensometer, as is comprahensible by the meaning of a word, as a instruments to magnify more vivid and accurate than the former by use optical lever.

The Tiltmeter is called as a "Tiltmeter with Horizontal Pendulum of Zöllner Suspension Type", consists of 2 horizontal pendulums of Zöllner Suspension as shown in Fig. 5 and to be recorded the enlarged axis rotations by aid of mirror on 2 rectangular co-ordinate axis.

The Discharge Meter is a instrument of weir box type to measure the water

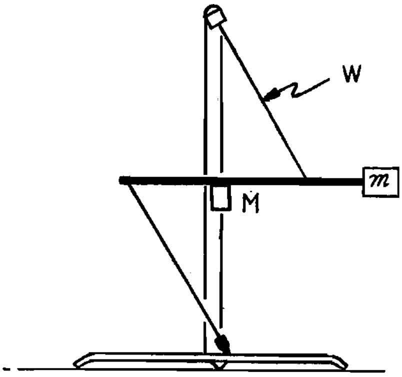


Fig. 5. Illustration of Tiltmeter. (take a side-view of pendulum)
M : mirror, W : Super-Invar wire (50μ in diameter) m': mass
It is constructed mainly of Super-Invar.

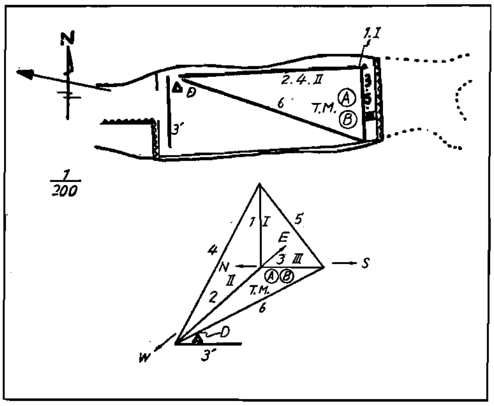


Fig. 6. Disposition of instruments interior the observation room.
The same marks are used as in Table 1.
Single arrow shows the direction of place of rock-falling.

level prepared a triangular notch in the side ditch. The arrangement of above mentioned instruments in the observation room is illustrated in Fig. 6.

Three componets of these Extensometer, 1, 2, 3, are set up verticaly to the ground, to E-W, and to S-N direction respectively, and all of them faced to rectangular co-ordinate axis. The other components, 4, 5, 6, are arranged obliquely intersecting each other with 2 components out of three mentioned above. The residual one 3′ is placed in parralell position to the component 3, in order to compare with it. The High Magnification Extensometer is provided for measuring 3 rectangular co-ordinate axis of 1, 2, 3.

Tiltmeter A and B are provided for the purpose of measuring the tilt on either direction of N 45°W - S 45°E and N 45°E - S 45°W.

The Discharge Meter is also accomodated to find the range of mine water accumurated which is infiltrated to the observation room.

The value of instrumental constant is shown in Table 1.

Extensometer.

	Length. (m.)	Direction.	Angle of Elevation. (degree.)	Senstivity. (10^{-6}/mm.)
1	4.300		90	5.54
2	4.950	N 88° E	0	4.92
3	1.900	N 2° W	0	10.74
4	6.575	N 88° E	50	3.46
5	4.800	N 2° W	66	2.78
6	5.120	N 77° W	0	2.30
3′	1.900	N 2° W	0	6.12

High Magnification Extensometer.

	Length. (m.)	Direction.	Angle of Elevation. (degree.)	Senstivity. (10^{-9}/mm.)
I	4.300		90	4.61
II	4.950	N 88° E	0	5.78
III	1.900	N 2° W	0	7.84

Tiltemeter.

		Direction.	Period. (sec.)	Senstivity. (10^{-2}″/mm.)
T.M.	A	N 45° E	25.6	2.0
	B	S 45° E	25.6	2.0

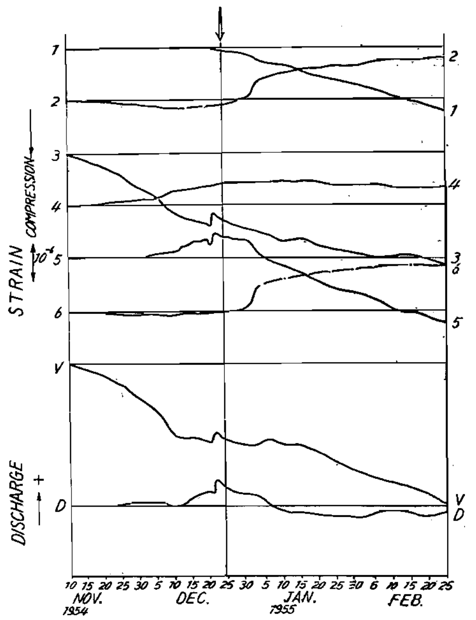
Discharge Meter.

D Sensitivity. 5.3 (10^{-3}cm./mm.)

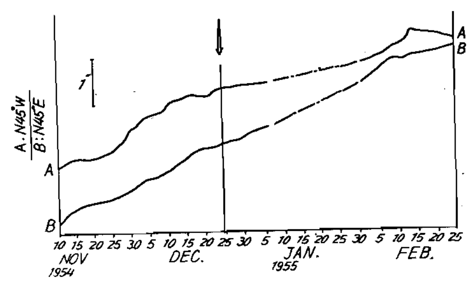
Table 1.

4. The result of observation.

The observed value of actual survey is consist of the variations combined



(a)strain and discharge.



(b) tilt

Fig. 7. Variations of strain, tilt and discharge. (excluded anuual variation) Double arrow shows the time of occurrence of the 1st rock-falling.

with both actual and annual value. It it therefore necessary to extract annual variation out of measurement value in order to obtain the actual variation. However it is pity to say, that the annual variation is not available in this observatory having been only short history of this establishment. For the shake of convenience, therefore, we take it between 1952-1953 for the annual variation here.

The variation before and after the event of rock-falling, from November 15th 1954 to February 25th 1955, is shown in Fig. 7 (a), (b) with the same marks used as in Table 1. The mark V stands for volum dilatation is obtained from components 1, 2, 3.

The Fig. 8 is the result obtained from the change of tile compounded with components A, B, by vector diagram. A part, marked with —·—·— on this diagram shown the period while no record had been written and remaining part of before and behind of above mentioned mark is obtained by actual survey. As we take notice of these variation, the data shows remarkable difference between before December 10th and thereafter. Those phenomenon are investigated as folloes.

On the variation to begin with, this sort of variation had been indicated normal change to certain direction up to beginning of December and thereafter the abnormal change had been taken place. Since rock-falling occurred the

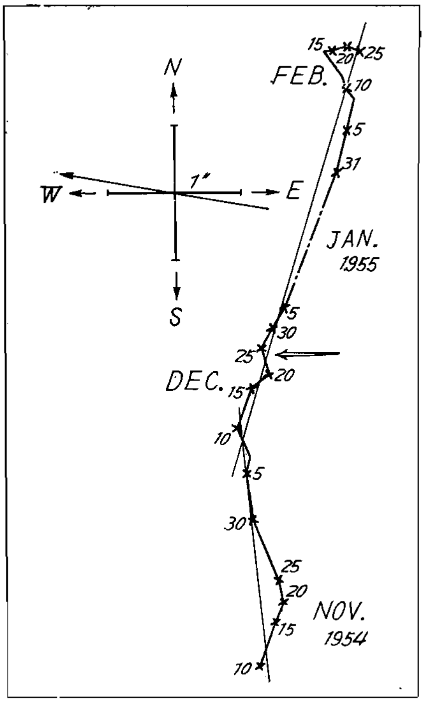


Fig. 8. Vector diagram of variation of ground tilt. (excluded annual variation) Single arrow shows the direction of place of rock-falling. Double arrow shows the time of occurrence of the lst rock-falling.

variation became bigger scale especially on and after several days of lst January, the remarkable change had been recorded on meter restoring bit by bit to normal variation.

It might well be deduced that in case of rock-breaking in the cource of nature, such as rock-falling stress distribution of nearby rock commence to change gradually for suitable period befor break down and once it occurs the rock transforms suddenly its shape different from as it was. According to the fact as mentioned above, it might be deduced that the variation indicated before December 10th seemed to be normal change which has nothing to with the rock-falling. On the contrary, it will be inferred that the variation thereafter might be caused by rock-falling. The change of both strain and discharge in connection with the rock-falling is shown in Fig. 9.

If the rock were considered to be homogeneous isotropic elastic body, the stress would come out in case of strain be found.

Principal stress σ_1, σ_2 and σ_3 are formed as follows;

$$\begin{cases} \sigma_1 = \dfrac{E}{1+\nu}\left\{\varepsilon_1 + \dfrac{\nu}{1-2\nu}(\varepsilon_1+\varepsilon_2+\varepsilon_3)\right\} \\ \sigma_2 = \dfrac{E}{1+\nu}\left\{\varepsilon_2 + \dfrac{\nu}{1-2\nu}(\varepsilon_1+\varepsilon_2+\varepsilon_3)\right\} \\ \sigma_3 = \dfrac{E}{1+\nu}\left\{\varepsilon_3 + \dfrac{\nu}{1-2\nu}(\varepsilon_1+\varepsilon_2+\varepsilon_3)\right\} \end{cases}$$

where

ε_1, ε_2 and ε_3 are principal strain,

E is Young's modulus,

and

ν is Porsson's ratio.

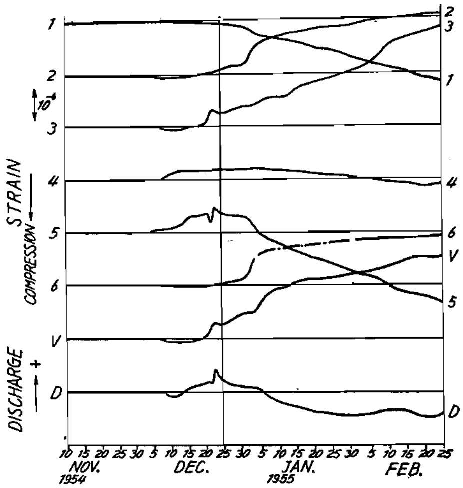


Fig. 9. Variations of strain and discharge concerning to the occurrence of rock-falling. Double arrow shows the time of occurrence of the 1st rock-falling.

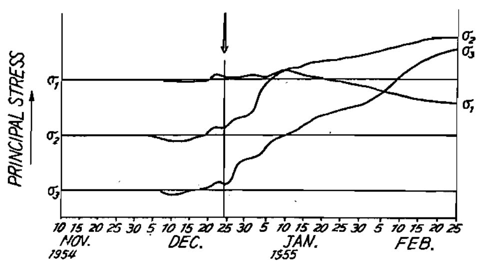


Fig. 10. Principal stresses obtained from strain.
Double arrow shows the time of occurrence of the 1st rock-falling.

From above relation, principal stresses σ_1, σ_2 and σ_3 obtained assuming as $\nu=0.25$ and ε_1, ε_2, ε_3 are strain of component 1, 2, 3, respectively which shown in Fig. 10.

In case of principal shear strain between component 1 & 2, 2 & 3, and 3 & 1 be ψ_{12}, ψ_{23} and ψ_{31} and G be modulus of rigidity, the principal shear stresses τ_{12}, τ_{23} and τ_{31} are formed as follows;

$$\begin{cases} \tau_{12} = G \cdot \psi_{12} \\ \tau_{23} = G \cdot \psi_{23} \\ \tau_{31} = G \cdot \psi_{31} \end{cases}$$

ψ_{12}, ψ_{23} and ψ_{31} can be obtained from not only 4, 5 and 6 components but also from 1, 2, and 3 components. The value obtained from former components marked with - - - - - and that of obtained from latter components marked with ——— is shown in Fig. 11. As a matter of fact these two values should be concorded with each other notwithstanding it shows similar figure as a whole. The difference of these two values seems to be considered caused by previous hypothesis.

It can be clearly noticed the change effected by rock-falling, shown the variation of Tiltmeter on Fig. 8. The variation of before and after 10th of December is quite different. It has been inclined to the direction of N 6°W with velocity of 0.060″/day up to 10th of December according to the indication but after that toward the direction of N 17° E with 0.039″/day. This variation is shown in Fig. 12 marked with ×. By this result the variation of tilt concern-

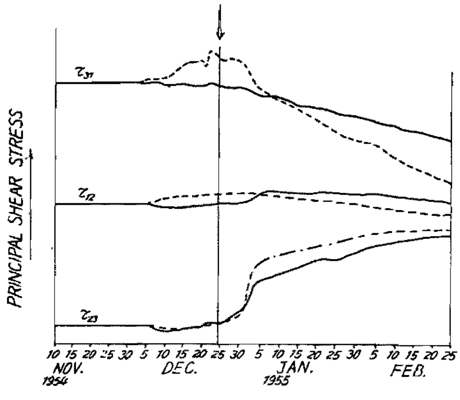


Fig. 11. Principal shear stresses obtained from strain.
——: from components 1, 2, 3
----: from components 4, 5, 6
Double arrow shows the time of occurrence of the lst rock-falling.

ing to rock-falling shall be with the velocity of 0.031″/day to the direction of S 34°E. The place of rock-falling is located to the N80°W direction from the observing point. Ground-tilt shifted to the opposite direction. If the rock were to be homogeneous isotropic elastic body, the variation of ground tilt would be obtainable from strains of 3 components 1, 2, and 3. This variation is illustrated with the mark ⊙ in Fig. 12, and this variation inclined to the S 6°W direction with velocity of 0.018″/day.

Though this fact can not be said to concord sufficiently with the result of observation, it is natural when we think about so uncertain hypothesis was applied as aforesaid.

As for the variation of Discharge Meter, however, it's change had been so small up to 10th of December, but thereafter it has been gradually increased. On the contrary after the event it has begun to decrease. This means that there exists same cause on the • variation of crack gaped the interior rock, effected by the change of stress.

Having a presentiment of

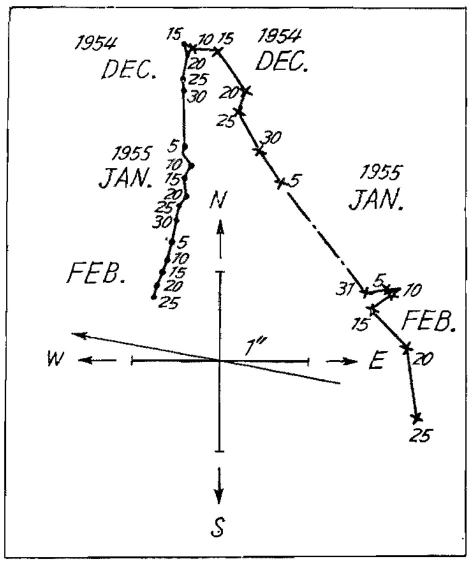


Fig. 12. Variation of ground tilt concerned with the occurrence of rock-falling.
×: observed with tiltmeter, •: calculated from strain. Single arrow shows the direction of place of rock-falling.

occurrance of rock-falling we may add the fact at the end of this chapter that the enormous change is observed on the Discharge Meter and 3, 5 components of Extensometer in this observation room.

5. Conclusion.

By the result of observation mentioned above, it is concluded that the omen of rock-falling is foreseen by the variation of nearby rock strain respectably long before the accident. Hence, it is deduced that to observe the state of rock strain is able to predict one of mine damage of the rock-falling to some extent.

At the conclusion of this report the writer sincerely wishes to express his hearty thanks to Prof. K. Sassa for his guidance and kind instruction given in the course of this work.